Bioacoustic Absorption Spectroscopy

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LONG TERM GOAL

Demonstrate the potential of bioacoustic absorption spectroscopy for tomographic mapping of the bioacoustic parameters of fish with swim bladders in shallow water.

OBJECTIVES

Develop a propagation model that accounts for the effects of bioacoustic absorptivity on transmission loss in shallow water at frequencies between 0.2 and 10.0 kHz. Develop a bioacoustic model that accounts for the resonance frequencies of absorption lines, which are due to dispersed pelagic fish, and schools of pelagic fish with swim bladders. Develop a model of the seasonal variability of resonance frequencies. Demonstrate consistency between absorptivity and echo sounder based estimates of number densities.

APPROACH

Design, construct and employ ultra-broadband (0.2 – 10 kHz), light weight, long term, autonomous source and receiving arrays, that permit inversion of bioacoustic parameters from transmission loss (TL) measurements. Conduct a series of bioacoustic absorptivity experiments in littoral seas in co-operation with fisheries biologists from the Southwest Fisheries Science Center. Design experiments to investigate the "signatures" of the two major classes of fish with swim bladders in time frequency space: physostomes (which have volumes that vary inversely with pressure) and physoclists (which have volumes that are independent of pressure). Develop a TL model that includes multiple bioacoustic absorbing layers with realistic shapes. Simulate effects of multiple absorbing layers on TL vs. time and frequency of physostomes and physoclists. Apply model to new and previously published bioacoustic absorptivity measurements, derive bioacoustic parameters of sardines and anchovies and other fish, and demonstrate consistency with trawling data. Formulate inversion algorithms that permit isolation and simultaneous inversion of bio and geoacoustic parameters from TL data. Invert bioacoustic parameters of fish with swim bladders (anchovies and jack mackerel) from bioacoustic absorption spectroscopy (BAS I and BAS II) experiments, which were made in concert with concurrent trawls in the seas off California. Demonstrate consistency between bioacoustic parameters derived from absorptivity and laboratory and at sea back-scattering measurements.

WORK COMPLETED

The first two bioacoustic experiments, BAS I and BAS II, which employed the recently developed ultra-broadband source and receiving arrays, were conducted in the Santa Barbara Channel in September 2001 and August 2002. BAS I data revealed absorption lines, which were consistent with the presence of 12.8, 10 and 6 cm long anchovies and 20 cm long jack mackerel. The presence of the 12.8 and 10 cm long anchovies was confirmed with concurrent trawls. The resonance frequencies of these lines were consistent with laboratory and at sea backscattering measurements. The presence of 6 cm long anchovies and 20 cm long jack mackerel was consistent with historical data. Initial results of BAS I have been documented and submitted to the ICES Journal of Marine Science. During BAS II the source was deployed at depths, which were above, below and in the middle of the absorption layer, and near the middle and bottom of the water column, to test the feasibility of inverting bioacoustic parameters from synoptic TL measurements at multiple source and receiver depths. During BAS II the concentrations of anchovies were extremely high; for the first time, trawls provided accurate estimates of the modal lengths of juveniles (6 cm). Analysis of bio-absorptivity data from BAS II will include the effects of tidally induced depth changes (± 1 m) and solitons. A three dimensional temperature array revealed that solitons propagated shoreward, essentially perpendicular to the acoustic propagation path.

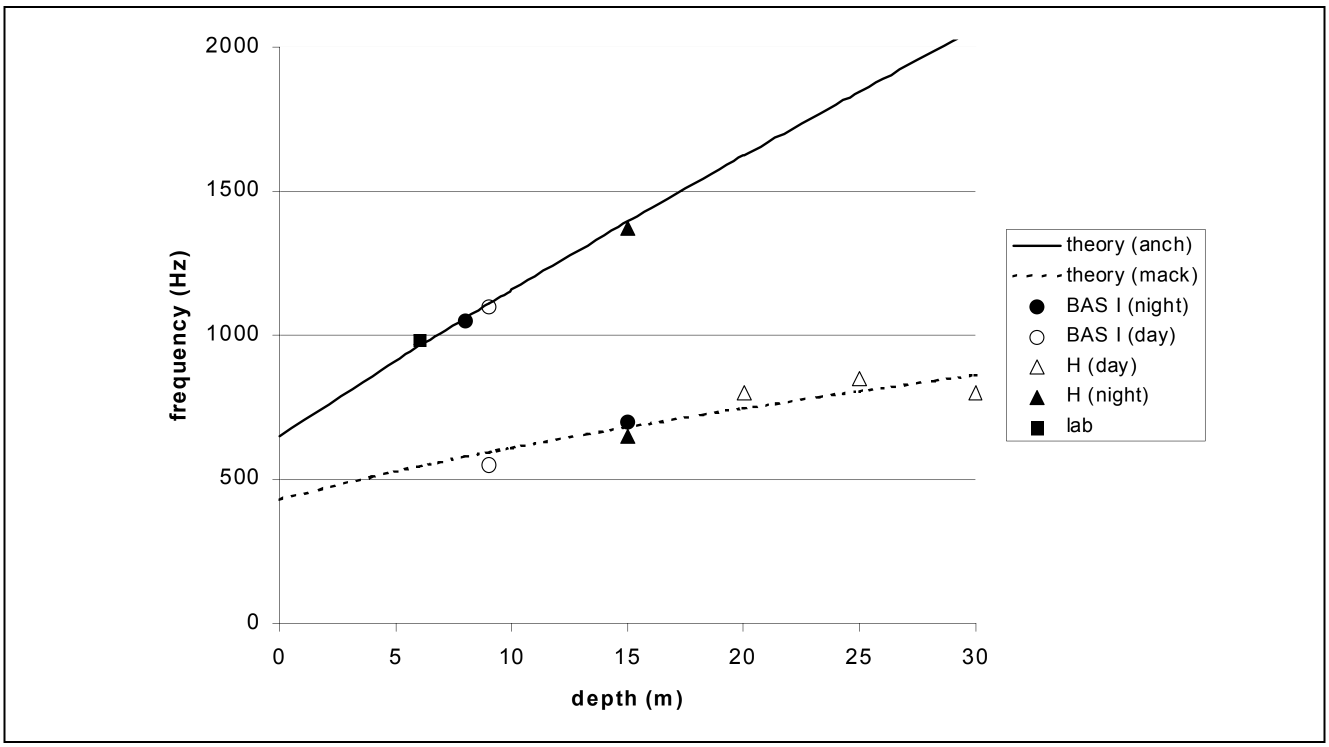

Figure 1. Calculations and measurements of resonance frequencies of 12.8 cm long anchovies and 20 cm long jack mackerel from BAS I, laboratory and Holliday's (H) back-scattering data in the Southern California Bight.

RESULTS

An inversion method has been developed that permits isolation and simultaneous estimation of bioacoustic parameters of fish with swim bladders and geoacoustic parameters of the bottom from TL measurements made between multiple source and receiver depths. This method will be applied to BAS II data during FY 03, but was first applied to experimental data reported by Qiu et al. (1999) in the Yellow Sea. These data were selected because 1) the bio-absorptivity at their site was extremely large, 40 dB, at a low frequency, 1.35 kHz, at short ranges, 1 - 5 km, and 2) measurements were made between two source depths and two receiving depths. This fortuitous combination of these parameters was considered ideal for demonstrating of the power of this method. The inversion was based on minimizing the rms difference, Δ, between measured and calculated values of TL at multiple ranges and multiple source and receiver depths, and involved a simultaneous search for bio-layer depth, bio-layer thickness, bio-absorption coefficient, geo-sound speed and geo-absorption coefficient.

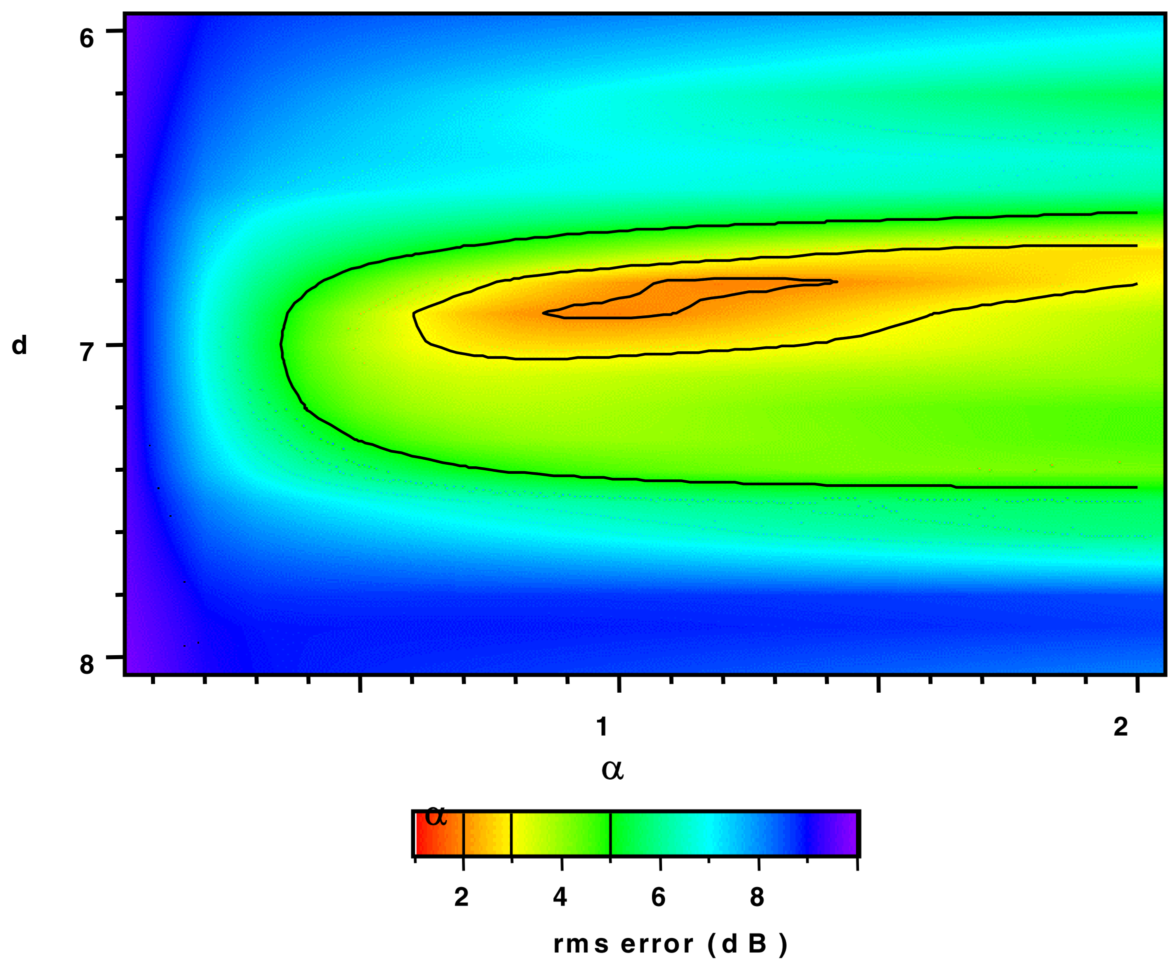

Figure 2. Ambiguity surface of the rms difference, Δ, between measured and calculated transmission loss (in dB) at 1.35 kHz as a function of layer depth, d, (m) and absorption coefficient within the layer, α (dB/λ). Minimum value of Δ: ± 1.7 dB at d = 6.8 m and α = 1.1 dB/λ. Contours: ± 2, 3 and 5 dB.

The resultant extremely small value of Δ, viz., ± 1.8 dB, confirms that the model, which was assumed in replica field calculations, was realistic, and that inverted parameters are meaningful. Figure 2 shows the ambiguity surface of Δ as a function of layer depth and bio-absorption coefficient at the resonance frequency of this absorption line, 1.35 kHz. The inverted depth of the absorption layer, 6.8 ± 0.3 m, was consistent with theoretical calculations of the depth (5.8 ± 1 m) of 10 cm long anchovies, the dominant species in the Yellow Sea, and with laboratory measurements of resonance frequencies of anchovies. The inverted layer thickness, ~ 0.3 m, was consistent with the nominal thickness of "thin" layers of phyto and zooplankton on continental shelves (Cowles, 1998; and Holliday, 1995). The inverted bottom sound speed, 1645 m/s, and geo-absorption coefficient, 0.14 dB/λ, were consistent with accepted bounds on these parameters. By contrast, inversion calculations, which assumed that that all excess attenuation at this site was due to the bottom, resulted in an unacceptably large value of Δ, ± 9.5 dB, and an unrealistic value of geo-alpha, 3 dB/λ. This powerful, new method for isolating the causes of attenuation, and classification of absorption lines requires only a few minutes of data. It is expected to replace "classification by observation of frequency shifts at twilight", which requires at least 6 hours of continuous, broadband measurements between fixed source and receiver. The next step will be to apply this inversion method to BAS II data, where the number of source and receiver depths was much larger: 8 and 16 respectively, and the bioacoustic parameters were, and the geoacoustic parameters soon will be measured.

IMPACT / APPLICATIONS

Naval applications: This research suggests that the detection range of naval tactical sonars may be significantly reduced when operating in strategic littoral environments, where concentrations of pelagic fish with swim bladders are large, such as the shallow seas off the coasts of the United States, Europe, China and the Gulf of Oman.

Fisheries applications: These results suggest that bioacoustic absorption spectroscopy measurements can be used to estimate number density vs. length (and possibly species) of pelagic fish with swim bladders in littoral environments.

TRANSITIONS

Naval Research Laboratory is supporting a four year 6.2 research program of experimental and theoretical investigations on the effects of bio-absorptivity on TL.

RELATED PROJECTS

Southwest Fisheries Science Center: biological sampling and fisheries sonar programs.

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PATENTS

I have been awarded a patent for the “bioacoustic absorption spectroscopy” method.